74220

DRAFT

Orange Soil
4567 grams

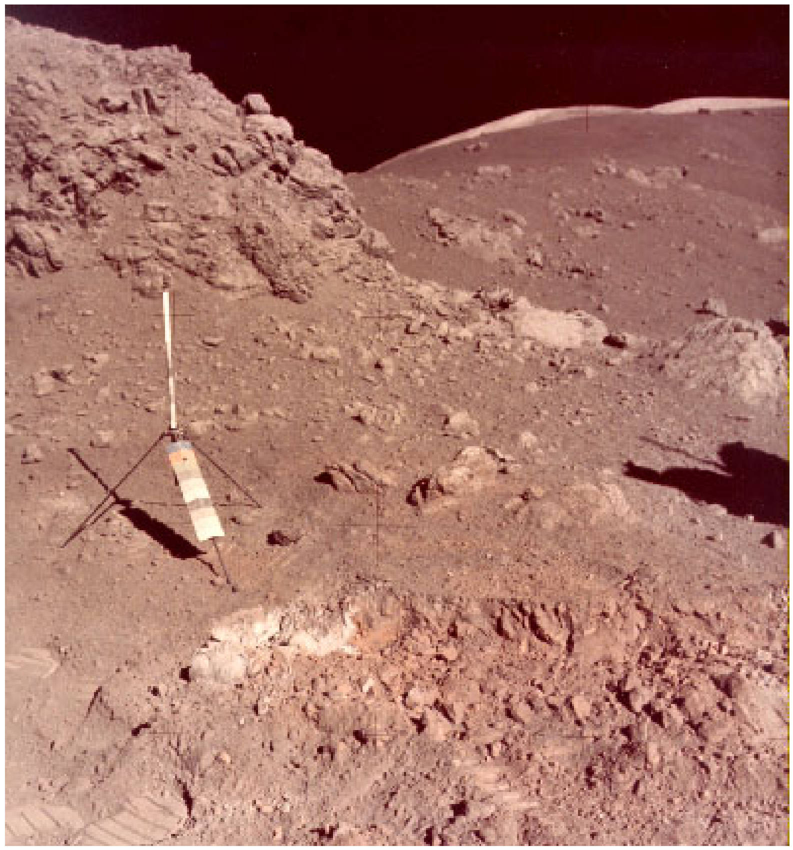

Figure 1: Photo of trench dug into orange soil at rim of Shorty Crater, Apollo 17. NASA AS17-137-20990 (see map and sketch in figure 20,21).

Introduction

The orange soil samples discovered at Shorty Crater, Apollo 17, consists of three samples of the trench pictured in figure 1 (74220, 74240 and 74260) and an adjacent double drive tube (74002-74001). 74220 and most of the drive tube are nearly pure orange glass, while 74240 and 74260 and the top 5 cm of the drive tube are mixtures of orange glass and local mare soil. A high portion of the orange glass in the drive tube is devitrified, and now black, due to fine olivine needles and ilmenite feathers. This is often referred to as "black glass", but compositionally, it is found to be the same as the orange glass.

The orange and black glass samples were identified as a pyroclastic deposit (Heiken et al. 1974, Meyer et al. 1975, Heiken and McKay 1977). Other origins (vapor condensation, impact) have been considered and rejected. Roedder and Weiblen (1973) considered an origin by meteorite impact into a lava lake, but this hypothesis has also been discounted.

Mafic volcanic glasses are found all over the moon (Delano 1986), but the Orange Soil (74220) and the Green Glass Clods (15425-7) are the "type samples"for pyroclastic deposits. The Orange Soil was found to be enriched volatile elements (Zn, Pb, S, Cl etc) and the glass beads were found to have a thin coating of condensed volatiles (Meyer et al 1975, Butler and

Orange Soil Samples

	Grams	Is/FeO	
74220	1180	1	surface sample
74240-4	924	5.1	trench sample
74260-4	527	5	trench sample
74002	909.6	0.2 to 3	drive tube, top
74001	1072	0.2	drive tube, bottom
total	4567		

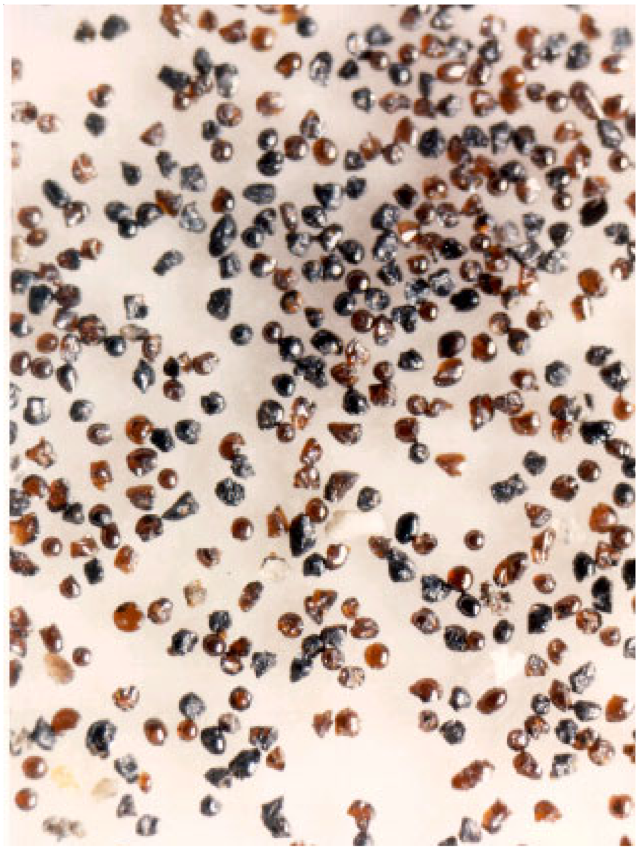

Figure 2: Sieved and washed fraction of orange soil, 74220. Particle size is 100 microns. NASAS73-15085.

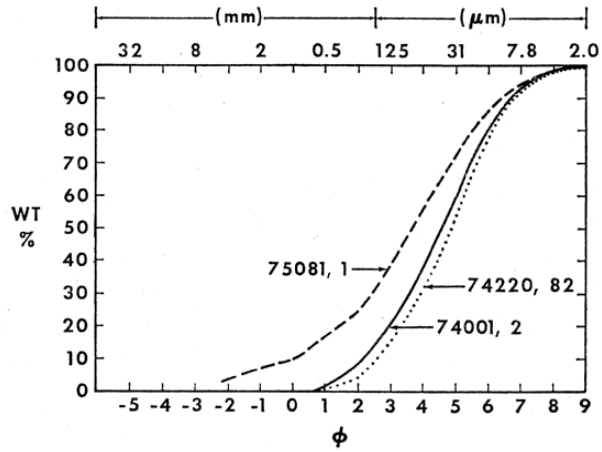

Figure 3: Grain size distribution of orange soil (74220) and core tube (74001) compared with typical soil (75081) (from Heiken et al. 1974). Mean grain size of 74220 is 40 microns.

Meyer 1976). The Orange Soil generally contains high levels of endogenous Ni (not due to meteorite contamination), as well as significant amounts of highly-siderophile-elements (Re, Os etc) that seem to be due to meteoritic contamination (Walker et al. 2004).

While the age of the orange glass is known to be about 3.6 b.y. (the same age as the mare basalts), the exact age of Shorty Crater has remained elusive (Eugster et al. 1981, Bogard and Hirsch 1978, Crozaz 1979). The cratering event that caused Shorty Crater would surely have modified these samples, as they were collected from the rim of the crater.

Petrography

Although the orange soil is nearly pure orange glass, only about 1/3 of the sample is unbroken spheres and ovoids, while about 2/3 is made up of broken spheres and angular glass fragments (Heiken et al. 1974, Heiken and McKay 1974). None of the glass in this sample is similar to lunar agglutinates, nor contains broken mineral or lithic fragments characteristic of impact glass. The average grain size of 74220 is ~ 40 microns (figure 3). The orange soil samples (as measured by the Is/FeO parameter) are extremely immature (Morris 1978, Morris and Gose 1977). Thus, this soil is not like that of other lunar soils and is interpreted as a pyroclastic deposit (Heiken et al. 1974).

Mineralogical Mode

	74220	74220	74240	74260	74001	74002top	74002 *(90-150 micron)*
reference	*Heiken and McKay 1974*					*McKay et al. 1978*	
Agglutinates	1.3 %	2.7	8	7.7		13.2	
Basalt	1.6	2	30	23.7		3.6	
Breccia	0.3	1.3	16.9	16.1		1.4	0.1
Anorthosite, Norite			0.6				
Plagioclase		1	4.6	2.7	1.6	0.1	
Pyroxene	0.3	0.3	11.3	13.7	0.3	1.4	
Olivine				0.3			
Ilmenite		0.3	1.3	2.3			
Glass							
Orange	66.3	83.6	4	7.7	8		
Black	29.3	6.7		2	73.3	91.1	99.9
Colorless	0.3		4.6	3.7			
Brown		1.3	2.6	1.7	16.6		
Ropy		0.7	14.3	18.1		0.1	
Other			0.3	0.3		0.3	

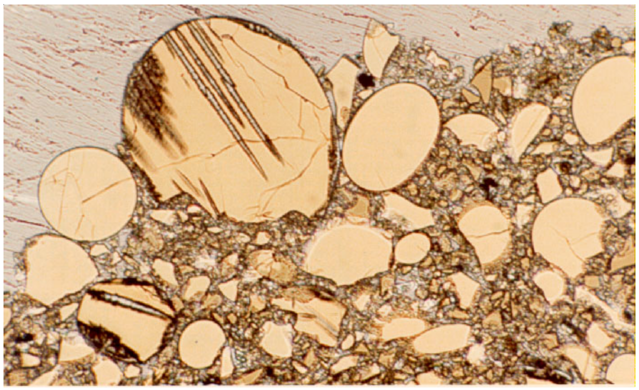

Figure 4: Photomicrograph of thin section of 74220 illustrating orange glass beads and broken fragments. The orange glass partially crystallizes olivine needles with fine ilmenite margins. Large bead in this photo is ~ 1 mm. NASA#S79-27295.

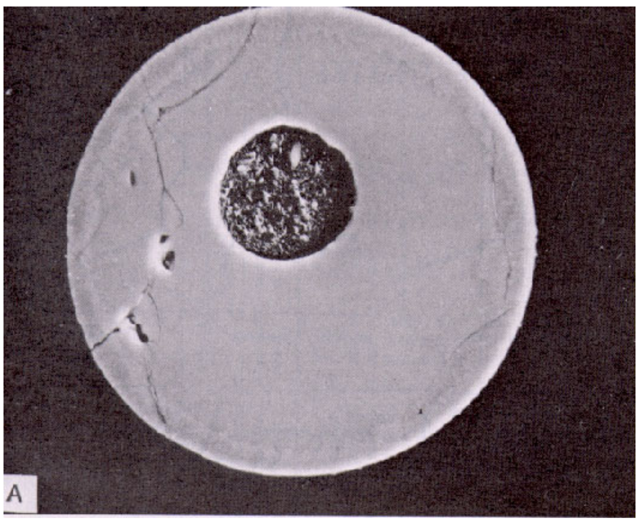

Figure 5: Rare vesicle in glass sphere from 74001 (from Heiken and McKay 1978). Diameter of sphere is 140 microns.

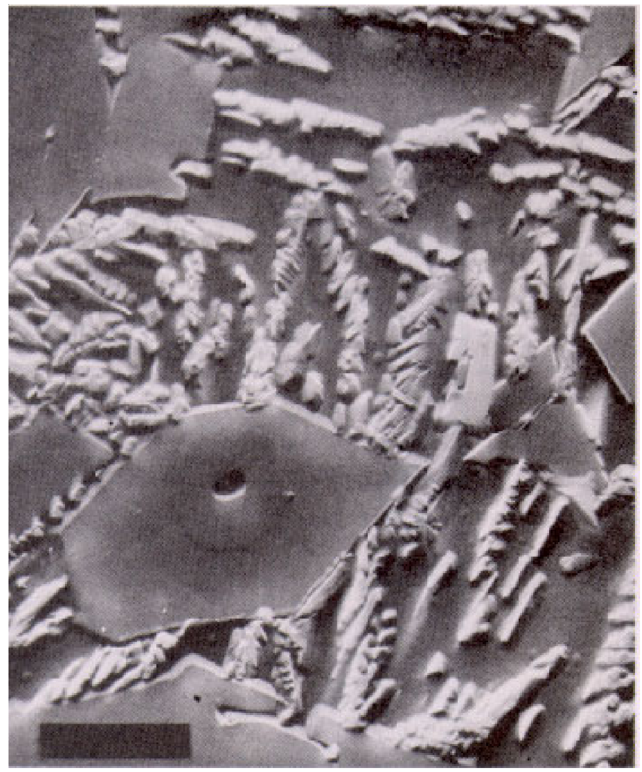

Figure 6: Scanning-electron-microscope image of ion-etched thin section of "black glass" droplet from 74002 ilustrating minute olivine, ilmenite and chromite quench crystals in glass matrix. Ilmenite feathers are bright in this BSE image, but they cause the black appearence of glass beads. From Heiken and McKay (1977). Black scale bar is 10 microns.

The orange soil is mostly orange glass beads and broken fragments of the same (figure 2). Heiken and McKay (1974) and McKay et al. (1978) determined the mineralogical mode and described the shape and crystallinity of the glass beads (see table). The petrography of the core (74002, 74001) is described in McKay et al. (1978). The core varies in its ratio of orange glass to devitrified black glass. Many beads are broken, presumably by the impact that made Shorty Crater. Few glass beads have vesicles (figure 5).

The devitrification features of the orange and black glass spheres in 74220 and 74001 are described by Haggerty (1974), Arndt and Engelhardt (1987) and Heiken and McKay (1978). Quench crystals of olivine and ilmenite (figures 4 and 6) make devitrified orange

Shape and Crystallinity of Glass Droplets (from Heiken et al. 1974, Heiken and McKay 1978)

Sample #	depth	droplet shape			crystallinity		
		sphere	ovoid	compound	glass	partly	crystalline
74002,179	5 cm	47 %	42	11	46 %	30	24
74002,181	18	46	37	17	15	19	66
74001,98	32	70	26	4	4	11	86
74001,113	44	53	34	13	2	9	90
74001,125	57.5	35	23	41	2	5	93
		sphere	ovoid	broken fragments			
74220,85A		20 %	5	74			
74220,85B		30	11	58			
74220,85C		20	5	75			
74220,85D		32	2	66			

glass appear opaque (black). These black glass droplets are found to have the same chemical composition as the orange glass (Heiken and McKay 1974). Olivine composition is Fo_{68-82} (Prinz et al. 1973, Taylor and Carter 1974 and Heiken et al. 1974).

The grey samples collected from the ends of the trench (74240 and 74260) also contain ropy glasses of presumed impact origin (Fruland et al. 1977, Korotev and Kremser 1992) as well as a variety of breccias and basalts.

The surfaces of the orange glass spheres are found to have a unique coating of micromounds (100 to 1000 ìm) (Heiken et al. 1974, Meyer et al. 1975, Clanton et al. 1978). In some places the coating has been scraped off (figure 7). The coatings were found to be made of mixed salts, with ZnS as a main component (figure 8). Very few micrometeorite craters were found on the surfaces of the spheres.

Surface-correlated volatiles

Tatsumoto et al. (1973) was the first to notice that the 74220 contained surface-correlated volatiles (Pb). Gibson and Moore (1973a,b) noted that 74220 was unusual as a lunar soil in that it gave off SO_2 at a low temperature (figure 13). By analyzing different size fractions, Thode and Rees (1976) showed that the sulfur was enriched on the surfaces of the grains, but they found that ^{34}S remained constant over different size fraction (unlike the case for all other lunar soils). Jovanovic et al. (1973) found that 74220 was enriched in Cl and Te and suggested that the source of high halogens was "fumarolic activity". Jovanovic and Reed (1974) and Wanke et al. (1973) found 74220 to be enriched in halogens (table 6) and Goldberg et al. (1976) showed the F to be a surface deposit (figure 9).

Meyer et al. (1975) and Wasson et al. (1976) hypothesized that halogens were in the vapor of the lava fountain, because of the increased volatility of various metals as chlorides and because some Cl and F was found on the surface of the glass. Cirlin and Housley (1977) used a technique that involved HF treatment to enhance thermal release of Pb, to show that the Pb was indeed present as $PbCl_2$ on the surface of the orange glass. Bell et al. (1974) reported evidence of $FeCl_2$.

Reed et al. (1977) and others have carefully studied the behavior of Zn, Pb and other elements during various kinds of leaching and conclude that although

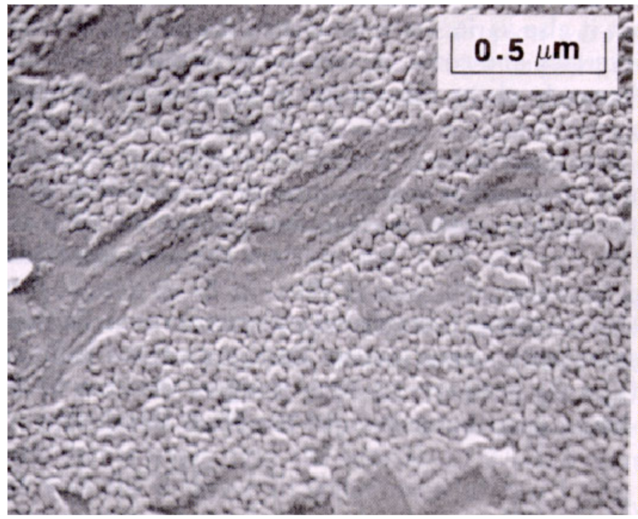

Figure 7: ZnS rich coating on glass sphere from 74001 (from Clanton et al. 1978).

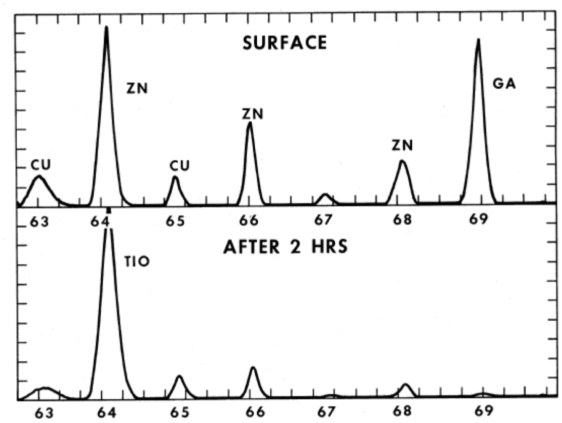

Figure 8: Ion microprobe mass scans of surface and ion-etched surface of orange glass sphere from 74220 showing that Zn, Cu and Ga were present in the surface deposit, but etched away after 2 hrs. of ion bombardment (Meyer et al. 1975).

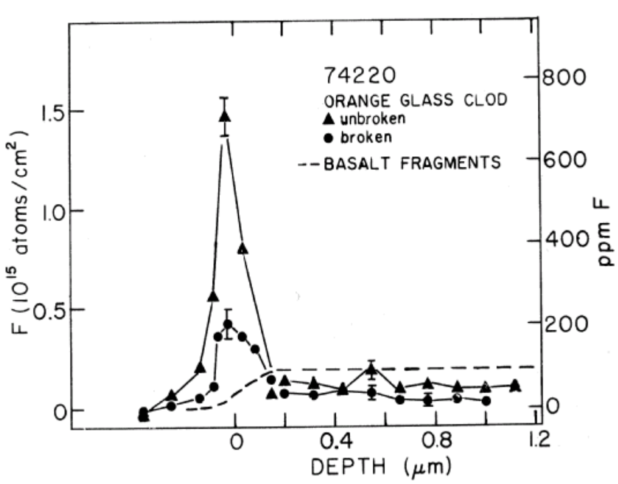

Figure 9: Flourine depth profile for samples of 74220 (from Goldberg et al. 1976)

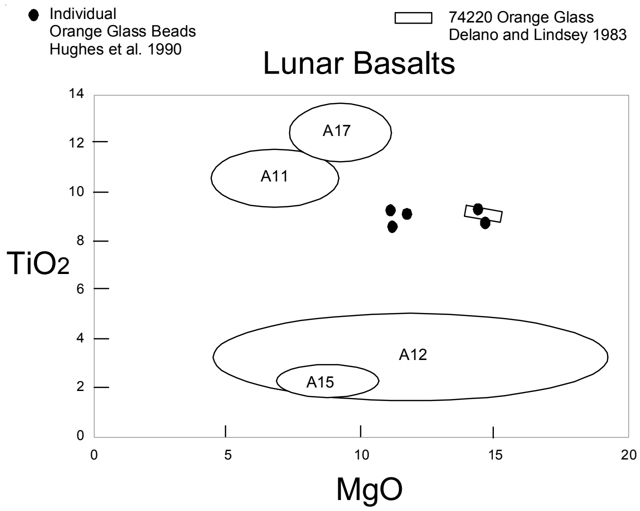

Figure 10: Orange glass compositions from 74220 (data from Reid et al. 1973, Delano and Lindsey 1983). Analyses of individual orange glass beads from other orange soil samples are variable (data from Hughes et al. 1990).

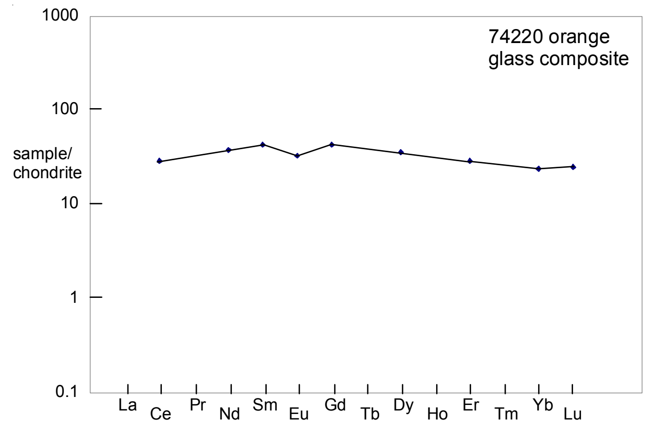

Figure 11: Normalized rare-earth-element pattern for composite of orange glass spheres from 74220 (data from Philpotts et al. 1974).

these elements are present in surface coating, they are not easily released. Krahenbuhl (1980) showed convincingly that Zn, Hg, Ge, Au and Ir were on the surfaces of the particles by carefully analyzing different grain sizes of the core tube 74002/1. Eugster et al. (1981) also showed that Br, and I were "anti-correlated" with grain size and thus on the surfaces of the glass beads. Meyer et al. (1975) used the ion microprobe to show that Zn, Cu, Ga, Pb and other elements were on the surfaces of glass beads from 74220. (figure 8). Butler and Meyer (1976) showed that the prevalent coating material (micromounds) contained sulfur. Nearly everyone agrees that the volatile element deposit on the glass beads was due to condensation of gas from volcanic eruption (figure 12).

Double Drive Tube 74002 – 74001

A 67 cm long double drive tube was collected from close to the trench at Shorty Crater. Nagel (1978), McKay et al. (1978), Morris et al. (1978), Bogard and Hirsch (1978), Blanchard and Budahn (1978), Crozaz (1978) and Heiken and McKay (1978) studied the double drive tube. Eugster et al. (1979, 1980, 1981) determined the age and exposure history of this important sample. Clanton et al. (1978) and Cirlin et al. (1979) studied the surface coatings on the particles.

Chemistry

There are at least three important, variable, chemical components to consider in understanding the orange soil (endogenous volcanic melt, volcanic exhalation, and meteoritic contamination). The volcanic exhalation is seemingly coupled to the endogenous component in time (Tera and Wasserburg 1976). Morgan and Wandless (1979) used volatile and siderophile element data from the core tube to unravel the contributions from meteorites and volcanic exhalations. Recently, Walker et al. (2004) have shown that the highly-siderophile-elements (namely Os) are greatly depleted in the orange glass.

Table 1 and figure 11 give the chemical composition of the bulk samples. Portions of the orange soil (74220) and the core (74002/1) are relatively uncontaminated by lunar regolith, and closely match the composition of the glass beads. However, in the bulk trench samples (74240 and 74260) and the top 5 cm of the core (74002), there is also a variable amount of mixing (by gardening) with lunar regolith.

Numerous investigators analyzed a large number of orange and black glass beads from Apollo 17 (table 5). Delano and Lindsey (1983) and Delano (1986) have identified several (~25) groups of volcanic glass, but found that the orange glass from 74220 was very constant in composition (figure 10). Hughes et al. (1990) analyzed some of the individual glass particles for a long list of elements (table 2).

Delano (1986) found that mafic volcanic glasses always have relatively high Ni, so Ni, at least, is not an indicator of meteoritic contamination in these samples.

The special feature of the orange glass samples is that they are found to be enriched in Zn, Cu, Ag, Cd, Tl, Br (and other metal halides) when compared to other lunar

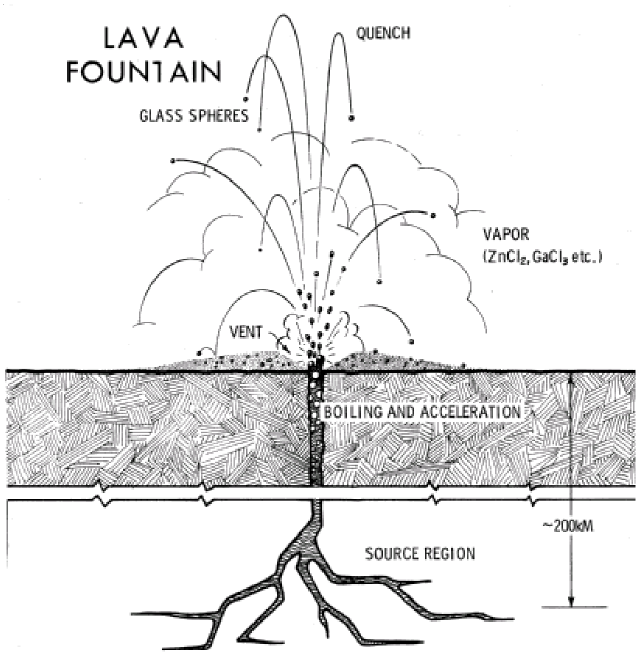

Figure 12: Sketch of hypothetical lava fountain that could have produced the features seen in the volcanic glass beads in 74220 (from Meyer et al. 1975).

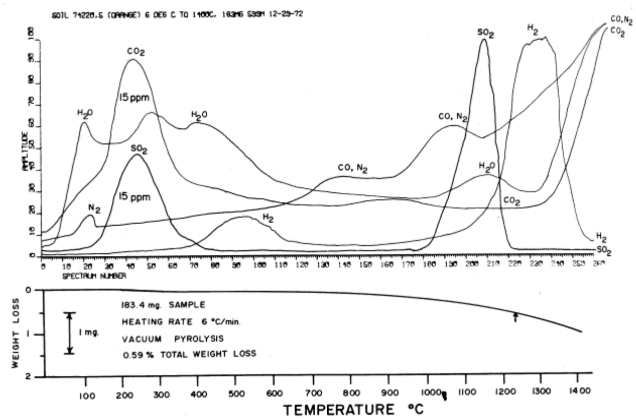

Figure 13: Gas release profile of 74220 showing low temperature release of carbon and sulfur species (from Gibson and Moore 1973).

samples (Morgan et al. 1974, Duncan et al. 1974) and this has been much discussed (see section of surface-correlated volatiles). Table 6 tabulates some of the analytical results for halogens and sulfur in the orange glass samples. While sulfur is not high in the bulk sample, it is an important component in the surface deposits (see Butler and Meyer 1976).

Various investigators (Walker et al. 2004, Krahenbuhl 1980, Wasson et al. 1976) have etched or leached the surfaces of the glass beads in an effort to separate the components (figure 14).

Radiogenic age dating

Husain and Schaeffer (1973), Huneke et al. (1973), Eberhardt et al. (1975), Alexander et al. (1978) and Huneke (1978) determined the age of the orange glass spheres by ^{39}Ar-^{40}Ar plateau (figures 15, 16 and table). In a "tour-de-force", Huneke dated individual glass beads at about 3.6 b.y. (figure 18). Tera and Wasserburg (1976) used the lead isotopes leached from the surface, along with the residue, to date the age of formation of the orange soil (figure 17). U, Th and Pd data for 74220, 74240, 74260 and 74001 are also given in Nunes et al. (1974), Silver (1974) and Tatsumoto et al. (1987). They note that ^{204}Pb is relatively high and easily released by mild thermal heating, or leaching.

Cosmogenic isotopes and exposure ages

Keith et al. (1974), Fruchter et al. (1978) and Murrell et al. (1979) determined the radioactivity of 74220 and 74002/1, due to cosmic ray interaction (table 4). Based on ^{22}Na, ^{26}Al activity, Fruchter et al. (1978) found that the top 2-3 cm of the core has been actively mixed with mare components (gardened) and about 2 cm of soil might be missing from the top of the core. Murrell et al. (1979) found the top of the core was undersaturated in ^{53}Mn.

Kirsten et al. (1973), Fleischer and Hart (1974), Hutcheon et al. (1974) and Crozaz (1978) reported nuclear track ages for orange soil samples (~ 10 m.y.).

Kirsten et al. (1973), Schaeffer and Husain (1973) and Hintenberger et al. (1974) reported the exposure age of 74220 as 30 m.y., 32 m.y. and 27 m.y., respectively. However, Bogard and Hirsch (1978) found that the data for the nearby core required a two-stage cosmic-ray exposure – 20 m.y. initially, followed by 10 m.y. (the presumed age of Shorty Crater). Eugster et al. (1977 and 1981) offer a different irradiation model based on an age of ~17 m.y. for Shorty Crater. The sample may have also been irradiated for up to 35 m.y., right after it erupted !

Another interesting discovery was that the Apollo 17 orange soil sample is unique among all lunar soils, in that it shows no surface ^{18}O, ^{30}Si or ^{34}S enrichment, which means it could not have been exposed to the lunar surface for any length of time (Taylor and Epstein 1974, Thode and Rees 1976).

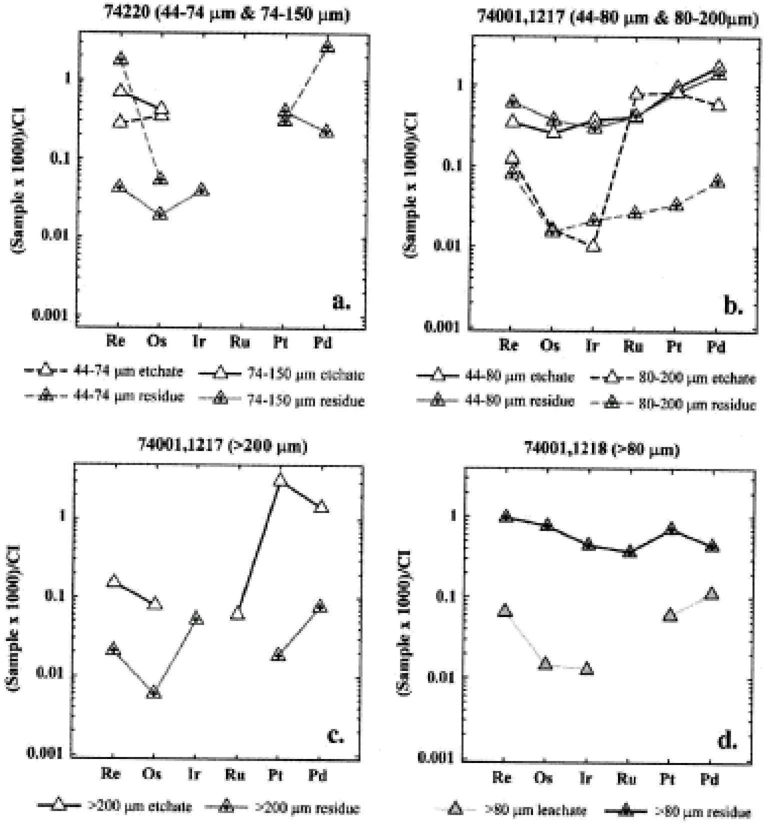

Figure 14: Concentration of highly-siderophile-element (HSE) elements in etchates and residue of hand-picked orange glass spheres (large and small), from 74220 and 74001 (core). Data and figure from Walker et al. (2004). See table 3.

Processing

The location of the trench and core tube on the rim of Shorty Crater are discussed in Muehlberger et al. (1973) and Wolf et al. (1981) (figure 20 and 21) and the samples were described in Apollo 17 PET (1973).

Only a portion of 74220 was sieved. In the sieving that was done, there were some orange glass clods that were found, but these remain unstudied. There also remain unsieved portions of 74240 and 74260 (figure 22).

Various investigators (e.g. Krahenbuhl 1980) sieved the samples to obtain results on different size fractions.

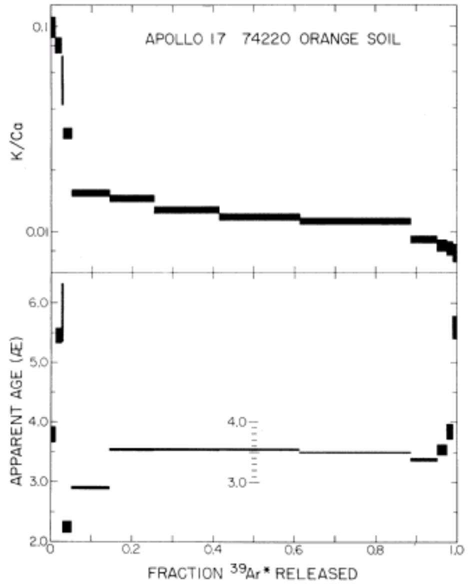

Figure 15: Argon release diagram for composite of orange glass spheres from 74220 (from Huneke et al. 1973).

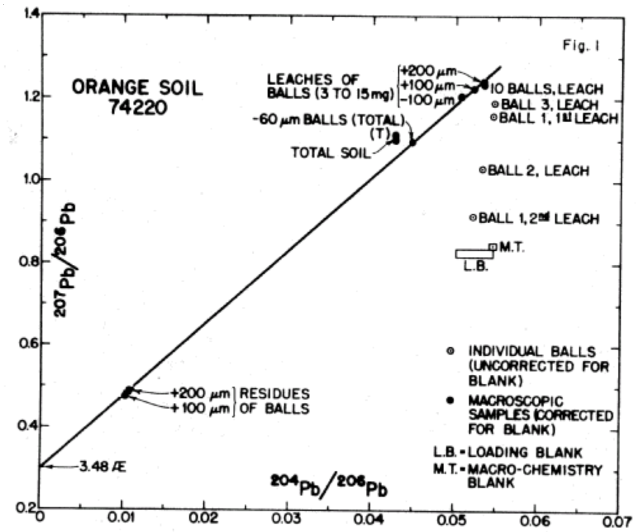

Figure 17: Pb/Pb diagram for orange glass spheres and composites from 74220 (from Tera and Wasserburg 1976).

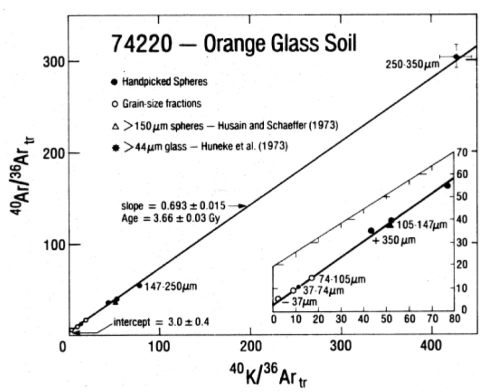

Figure 16: K/Ar data for orange glass from 74220 (from Alexander et al. 1978).

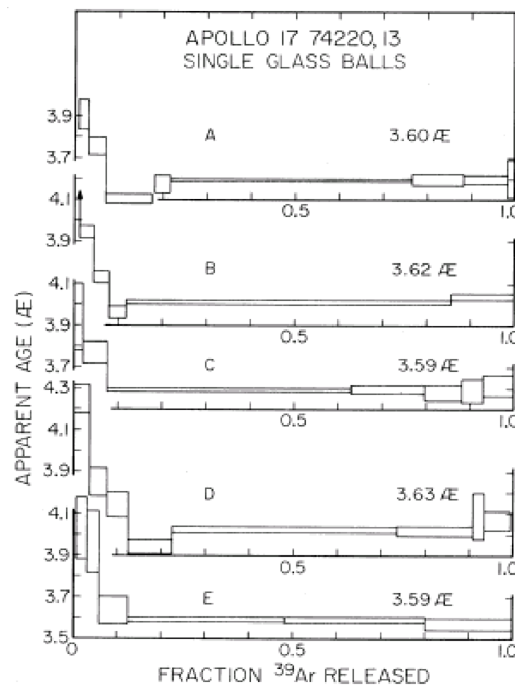

Figure 18: Argon release patterns for individual orange glass beads from 74220 (from Huneke 1978).

Summary of Age Data for 74220 and 74001

	Ar/Ar	Pb/Pb	74001 Ar/Ar
Husain and Schaeffer 1973	3.71 ± 0.06 b.y.		
Eberhardt et al. 1973	3.67 ± 0.04		
Eberhardt et al. 1975			3.66
Huneke et al. 1973	3.54 ± 0.05		
Huneke 1978	3.60 ± 0.04		
Alexander et al. 1978	3.66 ± 0.03		
Saito and Alenxander 1979			3.7
Tatsumoto et al. 1973		3.63	
Tera and Wasserburg 1976		3.48 ± 0.03	
Hutcheon et al. 1974	~3.7 (fission track age)		

Note: Beware decay constant.

Other Measurements for Orange Soil

Viscosity and heat capacity
- Uhlmann et al. (1973)

Magnetics
- Brecher A. and Morash K.R. (1973)
- Brecher et al. (1974)
- Olhoeft G.R. and Stangway D.W. (1973)
- Stone et al. (1982)

Isotopes
- Epstein S. and Taylor H.P. (1973)
- Taylor H.P. and Epstein S. (1973)
- Thode H.G. and Rees C.E. (1976)
- Silver (1974)
- Tatsumoto et al. (1973, 1978)
- Tera and Wasserburg (1976)

Rare Gasses
- Eberhardt et al. (1975)
- Eugster et al. (1977, 1979, 1980, 1981)
- Bogard and Hirsch (1978)
- Hintenberger et al. (1974)
- Kirsten et al. (1973)

Gas release
- Epstein S. and Taylor H.P. (1973)
- Gibson E.K. and Moore G. (1973)
- Gibson E.K. and Moore G. (1974)
- Jovanovic S., Jensen K. and Reed G.W. (1973)

Nuclear Tracks
- Crozaz (1978, 1979)
- Kirsten et al. (1973)
- Fleischer and Hart (1974)
- Hutcheon et al. (1974)

Experimental Petrology
- Green et al. (1975)
- Sato (1979)

Adsorption Isotherms
- Cadenhead and Stetter (1974)
- Cadenhead and Buerget (1974)

Depth Profile
- Murrell et al. (1979)
- Fruchter et al. (1978)

Surface features
- Carter et al. (1973)
- Holmes et al. (1974)
- Butler (1978)
- Grant et al. (1974)

Spectra
- Pieters et al. (1980)
- Mao et al. (1973)
- Vaughan and Burns (1973)

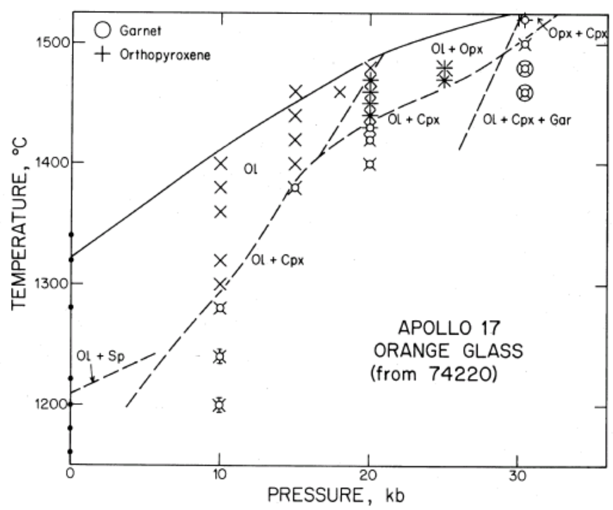

Figure 19: Experimental crystallization of 74220 orange glass at high pressure (from Green et al. 1975).

Table 1a. Chemical composition of Shorty Trench.

												core ave.
reference	Kieth 74	Rhodes 74	Wiesmann	Rhodes	Rhodes	Wiesmann	Rhodes	Nava 74	Nava 74	Rose 74	Rose 74	Blanchard 78
weight	*74220*	74220 (b)	74220 (a)	74240	74241	74241 (a)	74260	74220	74241	74241	74261	74001/2
SiO2 %		38.57		40.78	41.55		41.22	38.9	42.3	42	42.08	
TiO2		8.81	8.5	8.61	7.45		7.68	8.96	7.33	7.9	7.45	8.9
Al2O3		6.32		12.54	13.35		13.25	6.38	13.69	13.19	13.7	5.8
FeO		22.04		15.84	14.89		15.31	22.34	14.66	14.84	14.96	23.7
MnO		0.3		0.24	0.22		0.23	0.255	0.202	0.2	0.19	0.27
MgO		14.44		9.15	9.19		9.47	14.76	9.88	9.17	9.56	15
CaO		7.68		11.36	11.54		11.37	7.01	10.89	11.56	11.25	7.6
Na2O		0.36		0.38	0.48		0.38	0.43	0.48	0.43	0.42	0.42
K2O	0.082	0.09	0.084	0.12	0.12	0.12	0.12	0.076	0.123	0.14	0.13	
P2O5		0.04		0.09	0.1		0.09	0.097	0.124	0.1	0.09	
S %		0.07		0.14	0.12		0.12					
sum												
Sc ppm										59	57	48
V										75	70	
Cr			4650			2676				2874	3284	5200
Co										28	38	66
Ni		83		80	101		99			126	133	
Cu										28	32	
Zn		292		96	96		109			37	35	
Ga										10	10	
Ge ppb												
As												
Se												
Rb		1.2	1.107	2.3	2.5	2.423	2			1.8	2	
Sr		205	209	163	154	159	167			144	151	
Y		49		80	74		75			90	74	
Zr		182	185	235	232	218	239			352	286	
Nb		15		19	19		19			14	23	
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb												
Te ppb												
Cs ppm												
Ba			76.4			112				84	140	
La			6.25			9.95						5.9
Ce			19			28.8						21
Pr												
Nd			17.8			24						
Sm			6.53			8.55						6.9
Eu			1.8			1.6						1.88
Gd			8.52			12.6						
Tb												1.6
Dy			9.4			13.7						
Ho												
Er			5.1			8.07						
Tm												
Yb			4.43			7.45				10	7.2	4.2
Lu			0.611									0.59
Hf												6.3
Ta												1.2
W ppb												
Re ppb												
Os ppb												
Ir ppb												
Pt ppb												
Au ppb												
Th ppm	0.65					1.32						0.4
U ppm	0.164		0.16			0.37						
technique	*(a) IDMS, (b) XRF, (c) INAA*											

Table 1b. Chemical composition of Shorty Trench.

		spheres						bulk	500-62 micron						
reference	Philpotts 74 (a)			Korotev 92				Wasson 76						Wanke 73	
weight	74220	74220S	74241	74220	74241A	74241B	74261	74220	leach	etch	residue	total		74220	74241
SiO2 %				38.3	40.8	41.3	41.3						(c)	39.36	42.36
TiO2				8.8	8.7	7.6	7.5						(c)	8.09	6.49
Al2O3				6.8	12.9	13.8	13						(c)	6.52	13.9
FeO				22.4	16.2	15.4	15.8	23.8	0.68	2.56	20.97	24.19	(c)	21.87	15.18
MnO								0.275	0.01	0.03	0.23	0.272	(c)	0.25	0.19
MgO				14.28	8.8	9.02	9.68						(c)	14	9.27
CaO				7.8	11.1	11.4	11.1	6.16	0.18	0.01	6.16	6.43	(c)	7.4	11.4
Na2O	0.078	0.064	0.124	0.366	0.457	0.471	0.476	0.274	0.01	0.03	0.206	0.247	(c)	0.4	0.45
K2O														0.076	0.1
P2O5														0.048	0.1
S %															
sum															
Sc ppm				48.3	61	57.3	53.9	37	1	0.18	35	36	(c)	42.5	50.2
V														130	
Cr				4650	2780	2800	2950	5030	136	456	4460	5050	(c)	4030	2320
Co				61.5	26.3	26.7	30.2	68	2.4	6.7	60	69	(c)	55.5	24.5
Ni				113	90	140	120	110	3.6	8.9	71	83	(c)	67	82
Cu														25	21
Zn								194	43	5.3	17	65	(b)	270	88
Ga								16.1	2.9	0.79	2.5	6.2	(b)	16.5	13.4
Ge ppb								401	80	20	143	243	(b)	260	210
As														15	22
Se															
Rb	1.11	0.644	2.55											1.86	
Sr	206	205	155	235	170	210	140							160	140
Y														44	61
Zr	184	194	565	175	270	200	250							162	204
Nb														13	15.1
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb								314	122	7.2	28	157	(b)		
In ppb								29	6.6	0.41	0.71	7.7	(b)		
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm														0.078	
Ba	78.4	73.9	116	78	120	109	127						(c)	130	120
La				5.94	9.72	9.93	9.37	5.4	0.35	0.06	5.2	5.6	(c)	6.5	10.9
Ce	19.9	17.7	29.6	18.1	29	29.5	27	19	0.9	0.2	19	20	(c)	18	34
Pr														2.5	4.4
Nd	17.9	17.4	24.8	17	22	24	17							16	31
Sm	6.5	6.4	8.8	6.71	9.05	8.72	8.21	5.2	0.29	0.06	5.3	5.6	(c)	6.7	8.7
Eu	1.84	1.83	1.64	1.79	1.68	1.55	1.63	1.7	0.05	0.02	1.6	1.67	(c)	1.83	1.65
Gd	8.46	8.5	12.2										(c)	9.3	11.1
Tb				1.48	2.19	2.1	1.91						(c)	1.6	1.9
Dy	9.16	8.82	14											9.5	14
Ho														1.9	2.8
Er	4.82	4.59	7.85											5.4	
Tm															
Yb	4.2	3.96	7.6	4.31	7.78	7.52	6.95	4.1	0.16	0.05	3.7	3.9	(c)	4.24	7.3
Lu	0.627	0.608	1.14	0.59	1.12	1.09	0.96	0.5	0.02	0.01	0.51	0.54	(c)	0.58	1
Hf				5.79	7.59	7.21	6.98	5.4	0.16	0.65	5	5.8	(c)	5.3	6.4
Ta				1	1.26	1.19	1.18	0.9	0.02	0.11	0.75	0.88	(c)	1.1	1.3
W ppb														83	200
Re ppb															0.2
Os ppb															
Ir ppb				<6	3.5	4	4.5	0.35	0.03	0.04	0.19	0.06	(b)		7.9
Pt ppb															
Au ppb				<4	3.5	4	<6	1.01	0.08	0.02	0.244	0.34	(b)	1.5	2.6
Th ppm				0.42	0.99	1.24	1.1	0.61	0.02	0.09	0.58	0.7	(c)		
U ppm				0.13	0.4	0.26	0.23						(c)	0.15	0.37

technique (a) IDMS, (b) RNAA, (c) INAA

Table 1c. Chemical composition of Shorty Trench (cont.).

		bulk	spheres											
reference	Duncan 74	Morgan 74					Morgan 79			Krahenbuhl 80				Miller 74
weight	74220	74220	dark	orange	74001	74241	74001	74001	74001	74002	74002	74001	74001	74220
SiO2 %	39.03													39.58
TiO2	8.72									7.45	7.66	7.52	7.52	10
Al2O3	6.47													6.6
FeO	22.13													21.23
MnO	0.273													0.27
MgO	14.44													15.1
CaO	7.62													9.23
Na2O	0.34													0.47
K2O	0.077													
P2O5	0.043													
S %	0.073													
sum														
Sc ppm										47.9	47	47.6	45.7	46.9
V	132													
Cr	4680													3790
Co	62									62.8	63.6	62.3	60.3	63
Ni	74.7	67	70	72	68	64	66	51	53					
Cu	26.3													
Zn	253	230	45	141	148	86	178	185	151	196	103	140	134	
Ga														
Ge ppb		250	41	191	105	155	144	179	122	193	170	170	119	
As														
Se		640	129	460	350	340	380	490	353					
Rb	1.5	0.95	0.66	0.77	0.76	2.3								
Sr	200													
Y	43.8													
Zr	186													
Nb	13.6													
Mo														
Ru														
Rh														
Pd ppb							1.1	1.3	1.7					
Ag ppb		111	320	75	72	25	82	116	75					
Cd ppb		320	92	260	25	210	59	18	9	178	35.5	45.9	11.4	
In ppb		29					10	14	6.3	35.4	19.3	10	8.3	
Sn ppb														
Sb ppb		0.65	1	25	1.16	0.55	1.25	0.73	0.77					
Te ppb		62	10	49	38	24				79.3	50.8	105	61.9	
Cs ppm		0.053	0.03	0.045	0.037	0.107								
Ba	82													
La										6.11	5.85	6	5.64	7
Ce										29	26.7	31.4	26.6	
Pr														
Nd														
Sm														
Eu														1.9
Gd														
Tb														
Dy														
Ho														
Er														
Tm														
Yb														
Lu														
Hf														
Ta														
W ppb														
Re ppb		0.052	0.014	0.055	0.213	0.296	0.014	0.016	0.024					
Os ppb							0.045	0.049	0.035					
Ir ppb		0.411	0.114	0.214	0.021	2.78	0.042	0.048	0.016	0.024	0.019			
Pt ppb														
Au ppb		0.99	0.23	1.07	0.705	1.01	0.67	1.04	0.73	1.1	0.88	0.8	1.03	
Th ppm														
U ppm		0.168	0.13	0.115	0.141	0.33	0.143	0.15	0.151	0.138	0.126	0.16	0.148	

technique (a) IDMS, (b) RNAA, (c) INAA

Table 2. Chemical composition of Individual Glass Beads.

	74221,86				74,241,143			74,241,171	
reference	Hughes 90								
weight (a)	15.5	12.6	2.8	3	3.7	16	1.8	2.3	
SiO2 %	39.2	39.1	38.8	39	38.7	38.3	40.4	39.1	(c)
TiO2	9.2	9.3	8.7	8.7	9.8	8.8	8.6	9.6	(c)
Al2O3	5.9	5.8	5.8	5.8	6.5	5.9	7.8	6.3	(c)
FeO	22.3	22.5	22.9	22.8	23.1	22.9	21.3	22.6	(c)
MnO	0.29	0.26	0.26	0.27	0.28	0.28	0.3	0.31	(c)
MgO	14.5	14.7	14.9	15	12.2	15.1	12.2	12.8	(c)
CaO	7.4	7.2	7.4	7.3	8.3	7.6	8.4	8.1	(c)
Na2O	0.44	0.47	0.44	0.46	0.5	0.17	0.52	0.49	(b)
K2O	0.06	0.03	0.07	0.08	0.08	0.08	0.1	0.08	(b)
P2O5									
S %									
sum									
Sc ppm	45.4	46.3	47.6	46.7	49.8	48.2	47.8	49.2	(b)
V									
Cr	4310	4379	4516	4447	4584	4516	4310	4516	(b)
Co	58	59	61	60	59	61	51	51	(b)
Ni	27	96	75	18	123	108	68	69	(b)
Cu									
Zn									
Ga									
Ge ppb									
As									
Se									
Rb									
Sr	230	280	220	220	230	190	270	140	(b)
Y									
Zr	160	170	150	190	280	150	220	210	(b)
Nb									
Mo									
Ru									
Rh									
Pd ppb									
Ag ppb									
Cd ppb									
In ppb									
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm	0.04	0.05	0.15	0.19		0.06	0.05	0.14	(b)
Ba	120	59	161	31	80	129	79	124	(b)
La	5.3	5.6	5.7	6.2	5.2	6.6	7.9	6.3	(b)
Ce	16.7	15.2	16.2	18.4	18.6	18.7	21.2	18.4	(b)
Pr									
Nd	14.9	16.8	17.5	15.4	21.7	19.5	17.2	19.5	(b)
Sm	6.9	6.7	6.9	6.8	7.4	6.8	7.5	7.8	(b)
Eu	1.72	1.74	1.83	2.04	2.14	1.91	1.81	2.18	(b)
Gd									
Tb	1.42	1.49	1.42	1.65	2.02	1.77	1.5	1.89	(b)
Dy									
Ho									
Er									
Tm									
Yb	3.5	3.4	3.6	3.6	4.1	3.7	4.4	4.4	(b)
Lu	0.39	0.48	0.5	0.47	0.49	0.54	0.46	0.6	(b)
Hf	5.5	5.9	5.8	5.5	6.5	5.8	6.3	6.5	(b)
Ta	0.96	1.1	1.2		1.3	1.2	1.3	1.3	(b)
W ppb									
Re ppb									
Os ppb									
Ir ppb									
Pt ppb									
Au ppb									
Th ppm	0.3	0.3	0.35	0.04	0.48	0.22	0.65	0.77	(b)
U ppm	0.12		0.22	0.22	0.34	0.28	0.12		(b)

technique (a) micrograms, (b) INAA, (c) elec. Probe

Table 3: Highly Siderophile Elements in 74220 and 74001.

	74220		74220		74001		74001		74001		74001		
	44 - 74 micron		74 - 150 micron		44 - 80 micron		80 - 200 micron		> 200 micron		> 80 micron		
	etchate	residue	etchate	residue	etchate	residue	etchate	residue	etchate	residue	*leachate*	residue	
Ru	-	-	-	-	0.26	0.17	0.51	0.017	0.04	-	-	0.241	(a)
Pd	-	1.528	-	0.127	0.97	0.79	0.328	0.037	0.825	0.044	0.064	0.253	(a)
Re	0.0106	0.067	0.0264	0.002	0.013	0.023	0.046	0.003	0.0058	0.0008	0.0025	0.0372	(c)
Os	0.158	0.0245	0.189	0.009	0.116	0.167	0.0074	0.0068	0.0363	0.0026	0.0067	0.352	(b)
Ir	-	-	-	0.015	0.17	0.134	0.0046	0.0096	-	0.024	0.0058	0.205	(a)
Pt	-	0.265	-	0.346	0.83	0.712	0.706	0.0028	2.75	0.016	0.05	0.62	(a)

ppb by (a) ICP-MS, (b) IDMS neg. (c) calculated from Os isotope (Walker et al. 2004)

	74220	74241	74001
Ru	<1	3	<1
Os	0.7	0.8	20

ppb by Jovanovic and Reed 1974

	74220		74220	size fractions (microns)	
	500 - 62 microns		500	62	20
	l + e	residue	to 62	to 20	to 0.1
Au	0.86	0.274	0.34	0.605	1.7
Ir	0.65	0.21	0.06	0.28	0.38

ppb by RNAA (Wasson et al. 1976)

Table 4: Comic ray induced activity Orange Soil.

	ref:	depth (cm)	26Al dpm/kg	22Na	54Mn	56Co	46Sc	48V
74220	Kieth 74	~ 6.5	45	51	50	31	19.1	13
74002	Fruchter 78	0.3	78	125				
		0.75	85	142				
		1.25	75	135				
		1.75	71	110				
		2.75	54	103				
74001		7	48	74				
		37	33	38				
		57	33	29				

Table 5. Microprobe analysis of Orange Glass (groups).

	74220	74220	74240	74220				74001	74220	74220	74220	A 17
reference	Delano 81	Reid 73	Reid 73	Prinz 73	Carter 73	Glass 73	Roedder 73	Heiken 74	Mao 73	Philpotts	73	Warner 79
# beads	140	47	80			19		inc. black		red	black	47
SiO2 %	38.5	38.55	38.63	39.2	38	39.4	39.5	38.73	38.88	38	40.1	39.2
TiO2	9.12	8.87	8.96	9.4	8.87	9.3	8.56	9.46	8.7	9.6	9.9	8.9
Al2O3	5.79	5.85	5.87	5.8	5.51	6.02	6.41	5.98	5.76	5.4	6.3	5.9
FeO	22.9	21.96	22	22.4	22.4	22.7	22.2	22.6	22.21	23.4	23.8	22.4
MnO						0.3	0.32		0.24			0.28
MgO	14.9	14.99	14.79	14.1	14.5	15.5	14.4	14.2	15.81	17.3	15.1	14.6
CaO	7.4	7.16	7.31	7.6	6.99	6.42	7.13	7.73	7.17	6	7	7.2
Na2O	0.38	0.33	0.37	0.31	0.39	0.69	0.51	0.35	0.42	0.4	0.38	0.36
K2O			0.08	0.04	0.06		0.08	0.07	0.06			0.09
P2O5				0.04			0.05					0.04
S %												
sum												
Sc ppm												
V												
Cr	4721	3762	3762	4174	4789		3558	4037	5063			4584

Table 6: Halogens and sulfur in Orange Soil.

	Jovanovic 74					Wanke 73			Thode 76		Gibson 74			Gibson 78	
	74220	74220	74241	74001		74220	74241		74220	74241	74220	74220	74260	74001 - 2	74220
F ppm	102	61	230	<2	(a)	69	210	(b)							
Cl ppm	72	103	59	40		20									
Br ppb	1580	420	800	180											
I ppb	14	13	13	6											
S ppm									420	940	560	750	1080	548	820

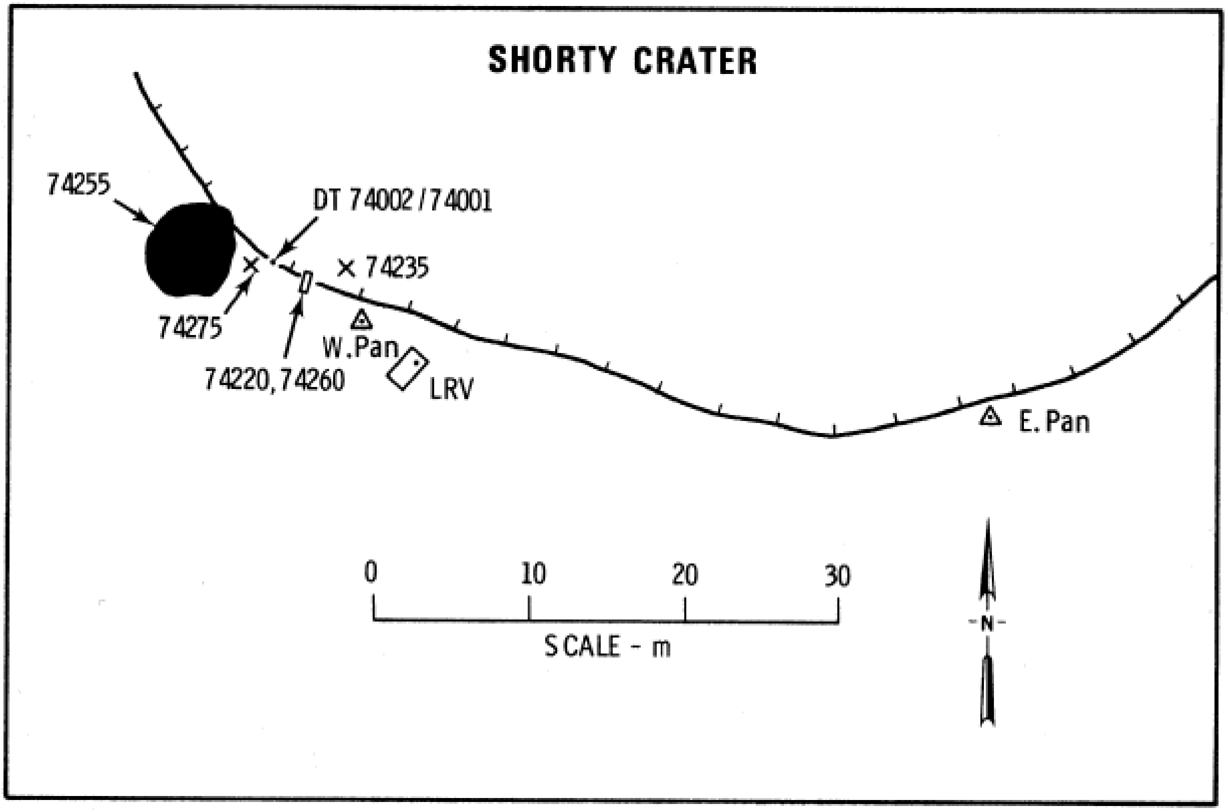

Figure 20: Map of Shorty Crater showing locations of samples. Figure 1 was taken from the position marked W. Pan.

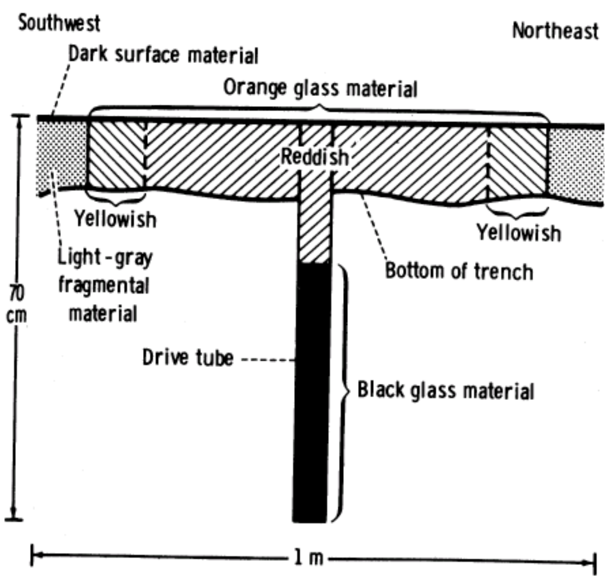

Figure 21: Sketch of trench and core tube on rim of Shorty Crater (from Muehlberger et al. 1973). The orange soil (74220) and the core (74002/1) were taken from the middle of the trench and the grey soils (74240 and 74260) from either end. The core was from just behind the trench.

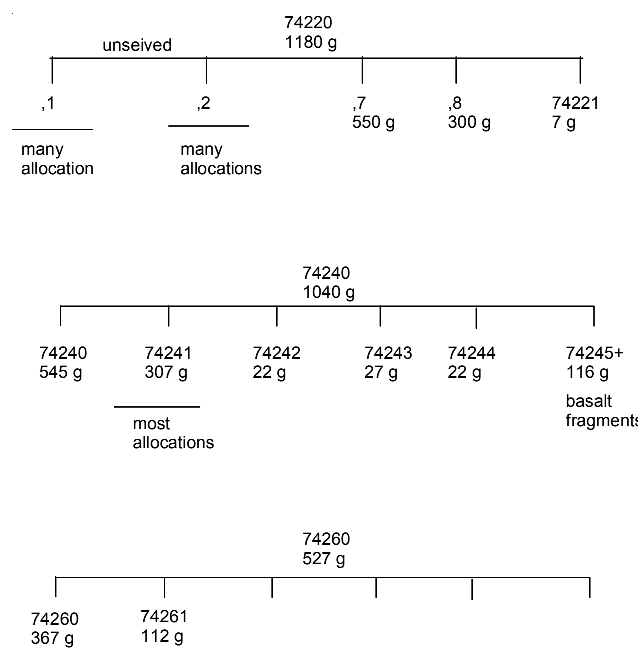

Figure 22: Top-level flow diagram of sample weights and allocations.

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